Chapter 3

Assessing I/I Levels and Reduction Technologies

To implement I/I policies in the RWSP, the King County Wastewater Treatment Division and the local wastewater agencies that it serves worked cooperatively to determine the extent of I/I in local collection systems and then to test methods to reduce I/I in local agency collection systems. Work began in 2000 with a regional flow monitoring and modeling effort and culminated in 2004 with the completion of 10 pilot I/I reduction projects. This chapter describes the approaches and results of these efforts.

3.1 Flow Monitoring

Starting in 2000, the County monitored wastewater flows during two wet seasons to assess I/I levels in local agency sewer systems.

3.1.1 Flow Monitoring Approach

Before installing flow meters, the County and local agencies identified and mapped model basins and mini basins:

- **Model basins** represent the sewered area flowing to specific flow meter locations. Each model basin consists of approximately 1,000 sewered acres and 100,000 lineal feet of pipe. There are 147 model basins in the King County Wastewater Service Area. Some of the model basins straddle agency boundaries because of agreements between agencies to "pass through" flows to the County conveyance system.
- **Mini basins** are further subdivisions of model basins that geographically isolate variation in I/I flow rates within the model basins. There are 650 mini basins in the service area. On average, each mini basin consists of 150 acres and 22,000 lineal feet of pipe.[1]

Approximately 800 flow meters were installed throughout the region in areas with separated sewers (Figure 3-1). The meters were first installed during the 2000–2001 wet-weather season. Because that winter brought an unseasonably low number of storms and yielded insufficient wet-weather flow data, the 2000–2001 data were used to calculate base flows only. The meters were reinstalled during the 2001–2002 wet-weather season to measure peak flows. Several rainfall

[1] There is an average of five model basins per local agency; the maximum number of model basins (17) is in Bellevue. The average number of mini basins in a model basin is five. The maximum number of mini basins per model basin is 13, and the minimum number is 1 (the model basin and the mini basin are the same). The average number of mini basins per agency is 23; the maximum is 117, once again in Bellevue. Five of the local agencies have just one mini basin.

events during the 2001–2002 season produced sufficient peak wet-weather flow measurements to calculate I/I volumes.

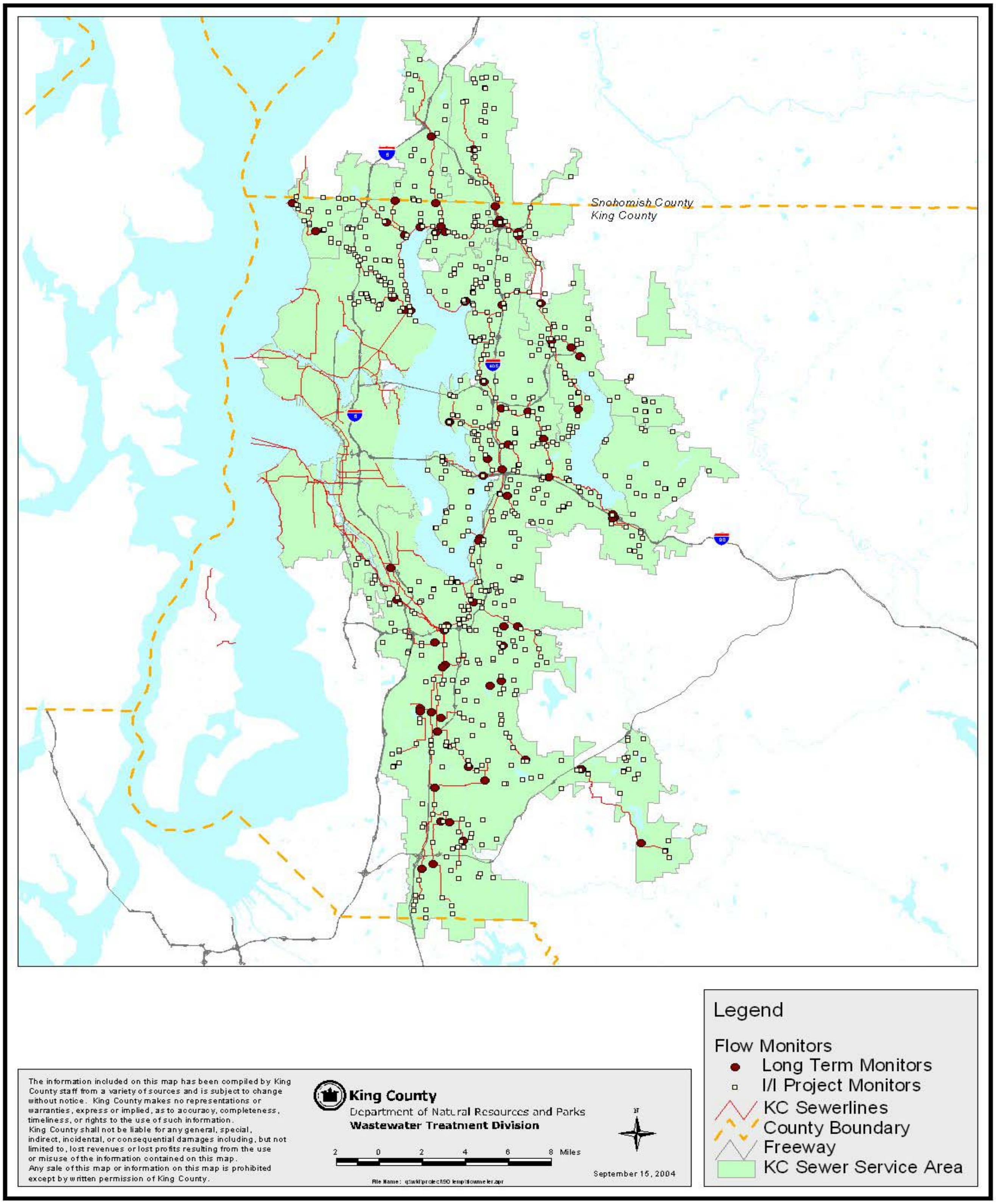

Figure 3-1. Flow Meter Locations

3.1.2 Flow Monitoring Results

Results of the 2001–2002 flow monitoring provided important information about the locations of the highest levels of I/I in the region and insight into the ways that I/I enters local agency collection systems and then the regional conveyance system. The results show a wide variation in I/I flow rates and volumes during storm events across the collection and conveyance systems. I/I flow rates in the various mini basins range from a low of less than 1,100 gallons per acre per day (gpad) to a high of over 65,000 gpad.

Information on how quickly I/I flows rise and fall in a particular mini basin during and after storm events helped to identify how I/I is getting into the systems. Rapid **inflow** of water that corresponds closely with a peak rainfall event comes mostly from private property, typically from downspout connections to the sanitary sewer system, cracked side-sewer pipes, foundation drains, and sump pumps. Although not typical, rapid inflow can also occur from public portions of the system, including storm drain connections to the sanitary sewer and leaky manholes. Slow **infiltration** of water into the collection system typically comes from saturated soils or groundwater and results in higher I/I flows remaining in the system for several days after the conclusion of a storm event. Slow infiltration typically finds its way into the system via leaky manholes, cracks in publicly owned sewer mains, and cracks in laterals that can either be publicly or privately owned, depending on the ownership rules in place in the jurisdiction.

3.2 Flow Modeling

After sufficient flow monitoring data were collected, King County and the local agencies used this flow monitoring data and other data to model existing flows and to project future flows in the system. The purpose of the modeling was to determine the condition of the regional conveyance system and to measure its long-term capacity to convey existing and projected wastewater flows.

3.2.1 Flow Modeling Approach

The County acquired new hydraulic modeling software—MOUSE™ (Modeling of Urban Sewers)—a PC-based computer model with a graphic interface to GIS. Use of a commercial modeling package rather than an in-house modeling program allowed the County and local agencies to easily share and analyze modeling results. The MOUSE™ modeling software was selected through a rigorous competitive process in which three software packages were evaluated for technical capability and cost. (For a description of the model selection process, see Appendix A1 of the *Regional Needs Assessment Report.)*

To ensure that modeled flow projections were accurate, the model was calibrated by comparing model results to measured data. Both the hydrologic and hydraulic components of the model were calibrated to base flow and I/I data collected during the 2000–2002 flow monitoring periods. Other inputs to the calibration included a 60-year rainfall record and basin-specific pipe and service area information. The calibrated basin models were then used to simulate I/I flows that could occur in the regional system over a 60-year period. The results of this 60-year simulation were used to estimate the 20-year peak flow in gpad for each model basin.[2] The estimated peak flow served as an indicator for the performance of each local agency system.

The general strategy for modeling I/I and wastewater flows was to input rainfall and flow data into the model and calibrate the continuous *hydrologic* portion of the model to the rainfall response for the model basins and mini basins in the regional service area. Once good calibration was achieved, a long-term (60-year) rainfall data set was used to “run” each model basin to model long-term flow. The modeled long-term flows were analyzed statistically to determine the 20-year peak flow produced in each model basin. These peak flows from the model basins were applied (input) to a hydraulic model of the County conveyance system. The *hydraulic* model was then run to analyze how the system performs under existing 20-year peak flow conditions.

Definitions of Modeling Terms

Hydrologic model. A model used to numerically simulate the physical process of rainfall becoming I/I.

Hydraulic model. A model of the actual pipes that convey the wastewater and I/I generated by the hydrologic model. The hydraulic model outputs flow depths and velocities in specific pipe segments and allows for the evaluation of system performance under existing and future demands.

Basin. A geographic area that contributes flow to a specific location, usually a flow meter or a facility. The two primary types of basins used in the assessment are **model basins** and **mini basins**.

Model calibration. The process of adjusting model parameters so that the model output matches the measured sewer flow for the same time period.

Once the existing 20-year peak flows for the current conditions were established (assumed to be year 2000), future flow conditions were projected. The projections involved applying assumptions related to sewered growth, existing I/I rates, and I/I rates from areas to be served by sewers in the future. For a more detailed discussion of the flow modeling process, see the *Regional Needs Assessment Report.*

3.2.2 Flow Modeling Results: I/I Flow Projections

Figures 3-2 and 3-3 illustrate the projected peak I/I flow rates by model basin and mini basin for the portion of the regional service area served by separated sewers. The figures show that projected peak I/I levels in the basins vary from less than 1,100 to over 30,000 gpad and that relatively low and high projected peak I/I flows are dispersed throughout the region. Any approach to reducing I/I levels would need to account for this variation by implementing projects on a case-by-case basis across the region.

Everyday examples of flow rates…

- A rate of 1,440 gpad would be produced by a flow of 1 gallon per minute from 1 acre of land. A single continuously running flow-restricted kitchen faucet typically produces 1 gallon per minute of flow.
- A rate of 4,320 gpad is the same as the flow produced by a continuously running shower, which typically flows at about 3 gallons per minute.
- A rate of 7,200 gpad would be the equivalent flow produced from an unattended garden hose, which typically produces a flow of about 7 gallons per minute.

[2] The County defines peak flow as the highest combination of base flow and I/I expected to enter a wastewater system during wet weather at a given frequency that treatment and conveyance facilities are designed to accommodate.

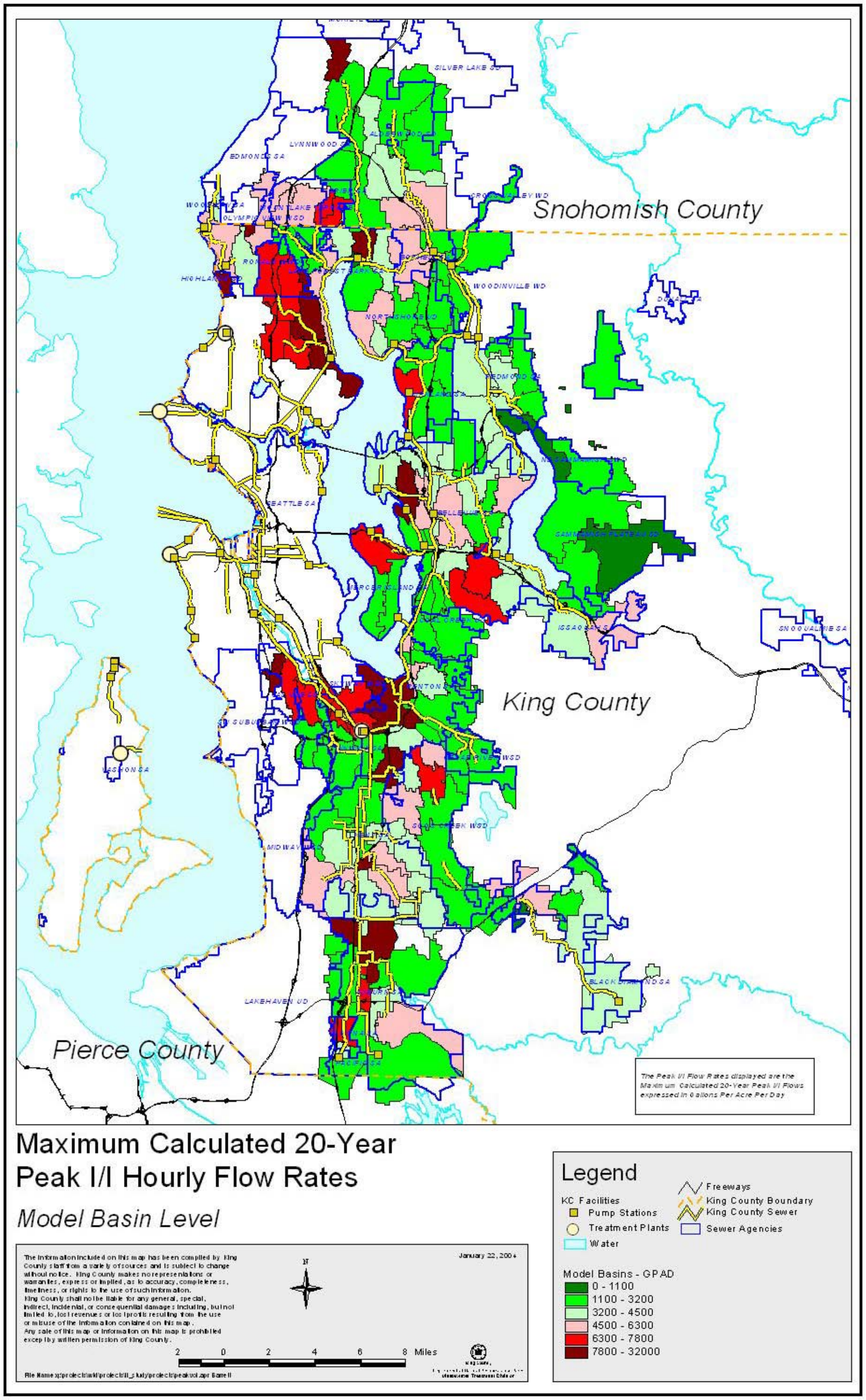

Figure 3-2. Peak Flow Projections for Model Basins

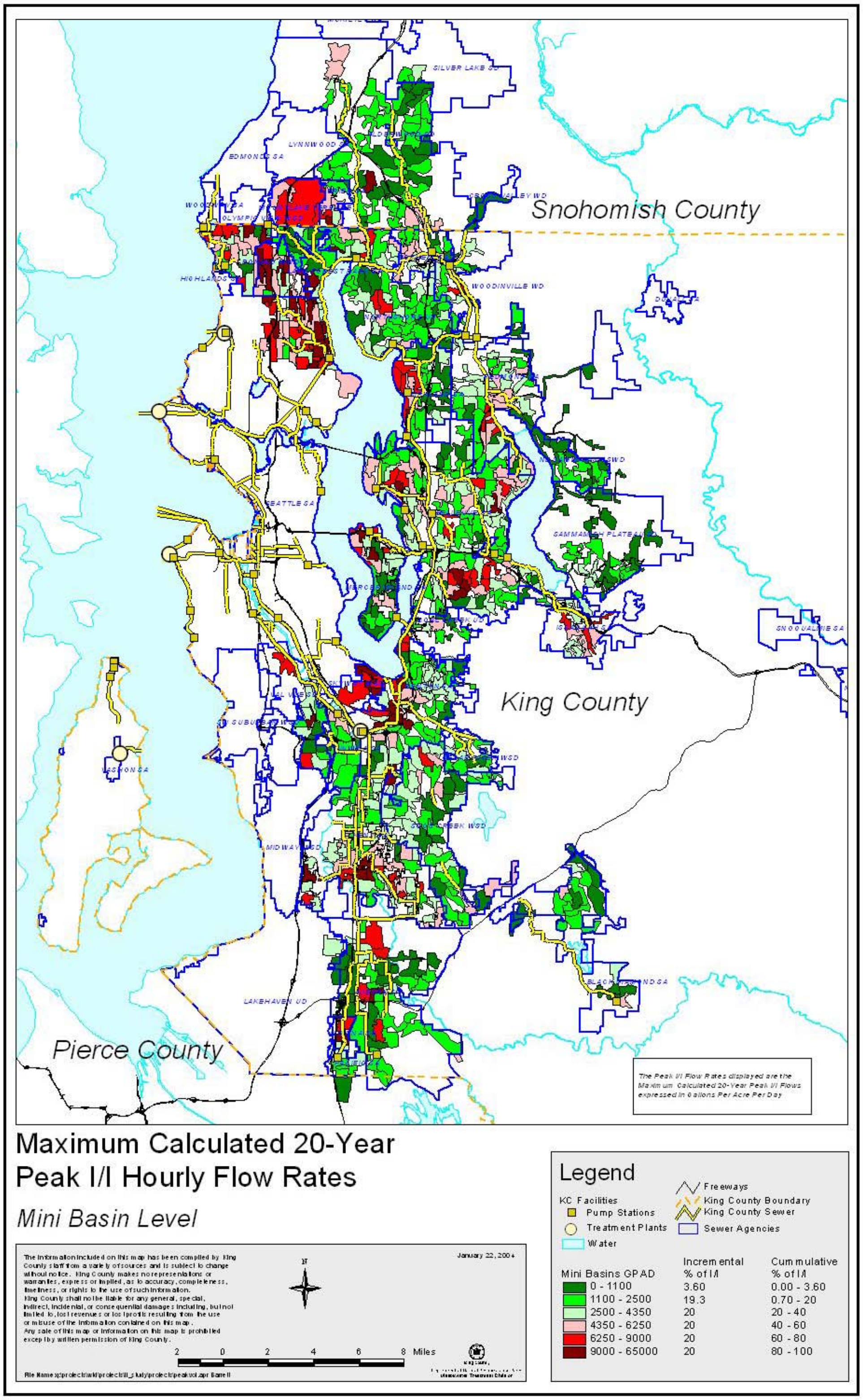

Figure 3-3. Peak Flow Projections for Mini Basins

3.3 I/I Reduction Analysis

King County and the local agencies conducted two major analyses to determine the feasibility of reducing I/I levels through rehabilitating collection system components: (1) a national review of I/I programs and (2) implementation of 10 pilot I/I reduction projects in the region.

3.3.1 National I/I Program Review

In 2001, a survey was conducted of nine wastewater agencies similar in size and function to King County's Wastewater Treatment Division. A key objective of the survey was to gather information about I/I reduction approaches that have worked elsewhere and their applicability to King County's service area.

3.3.1.1 Survey Approach

Table 3-1 lists the names and locations of the nine wastewater agencies that were surveyed. The surveys focused on gathering the following information from each agency:

- Catalysts for implementing local I/I reduction programs
- Rehabilitation methods employed
- System components rehabilitated
- Cost and effectiveness of rehabilitation methods
- Applicability to the regional program

Table 3-1. Agencies Surveyed for I/I Reduction Programs

Agency	Location
Bureau of Environmental Services	Portland, Oregon
Clean Water Services	Washington County, Oregon
Detroit Water & Sewerage Department	Detroit, Michigan
East Bay Municipal Utility District	Oakland, California
City of Houston Public Works Department	Houston, Texas
Metropolitan Council of Environmental Services	Minneapolis-St. Paul, Minnesota
Metro Water Services	Nashville, Tennessee
Miami-Dade Water & Sewer District	Miami, Florida
Milwaukee Metropolitan Sewer District	Milwaukee, Wisconsin

3.3.1.2 Survey Results

The I/I reduction programs in the agencies surveyed were primarily prompted by regulatory or court action and also by the need to provide capacity for tributary agencies. For example, the need to provide capacity is driving Milwaukee to develop a regional I/I reduction program that will include rehabilitation of its trunk lines. The construction of a major new interceptor in Milwaukee has now made the original trunk lines available for inspection and rehabilitation. Many agencies such as East Bay have completed system rehabilitation as part of their original I/I programs and are continuing to rehabilitate as part of their overall maintenance programs.

The rehabilitation methods used most extensively are cured-in-place pipe lining (CIPP) and dig-and-replace. Other rehabilitation methods reported include fold-and-form, pipe bursting, point repairs, slip lining, manhole coatings, pressure grouting, and manhole seals.

Lateral rehabilitation constituted a major portion of the rehabilitation efforts of several of the agencies surveyed, including Nashville, Miami, Washington County, Oakland, and Portland. The Nashville, Oakland, and Portland I/I reduction programs included rehabilitation and replacement of the portion of the laterals located on private property (side sewers). Lateral rehabilitation methods were primarily CIPP and dig-and-replace.

Most of the agencies surveyed conducted little or no post-rehabilitation flow monitoring to quantify the I/I removed from their systems and, in general, did not rigorously quantify the cost of I/I removal for specific rehabilitation projects.

3.3.1.3 Applicability to King County’s I/I Program

A common finding from the agency surveys was that rehabilitation of privately owned laterals and side sewers was an important component in achieving measurable reductions in I/I levels. Total basin rehabilitation—rehabilitation and/or replacement of mains, manholes, laterals, and side sewers in a basin—ultimately appeared to be the most effective solution for significant I/I reduction and could serve as an appropriate approach to rehabilitating portions of the collection system that have uniformly degraded over time.

The survey results helped to reinforce the approaches that were considered in designing and constructing pilot I/I reduction projects in the region. King County and the local agencies were interested in testing “trenchless” rehabilitation technologies, such as pipe bursting and slip lining, that had been successfully employed in other regions of the country and in testing the effectiveness of rehabilitating privately owned side sewers and laterals. The fact that trenchless technologies and rehabilitation of privately owned system components were common elements of successful I/I reduction programs elsewhere reinforced the decision to include these elements in pilot I/I reduction projects here.

The survey results were not as useful in helping to devise a method of measuring the cost-effectiveness of I/I reduction. The County and local agencies therefore jointly developed a detailed method for estimating the costs and benefits of I/I reduction projects. (See Chapter 4 for a complete discussion of the costs and benefits of I/I reduction.)

3.3.2 Pilot I/I Reduction Projects

RWSP Policy I/IP-2 directs King County to work cooperatively with local agencies to select and complete pilot I/I reduction projects. The pilot projects were completed in 2003 and 2004. The purposes of the projects were as follows:

- Demonstrate the effectiveness of various I/I reduction technologies in local agency sewer systems tributary to the regional conveyance and treatment system.
- Generate data regarding the unit costs for various reduction technologies and the effectiveness of the various technologies tested.
- Learn about the effectiveness (both in terms of cost and I/I reduction) of working on publicly and privately owned portions of the collection system.

The scope and scale of the pilot projects were governed by the County's $9 million pilot project construction budget. Data generated from the pilot projects were instrumental in providing inputs to the I/I benefit-cost analysis described in Chapter 4. However, none of the pilot projects, either individually or collectively, was of sufficient scale to test the cost-effectiveness of I/I reduction in relation to constructing larger conveyance system components. Field testing the cost-effectiveness of I/I reduction would require the construction of an I/I reduction project at a scale large enough to reduce peak flows to a point where a planned conveyance system improvement project is delayed, downsized, or eliminated.

3.3.2.1 Pilot Project Selection

The local agencies developed 10 criteria to be used to select the locations of the pilot projects and the types of technologies to be implemented in the projects. Projects were to be distributed throughout the region to provide geographic balance. The other nine criteria were as follows:

- Meet constructability time frame for the I/I program, including permitting needs
- Consider differing geologic conditions/do no harm
- Provide environmental and public health benefits
- Address private sewer issues
- Provide a regional impact
- Serve as useful models for future I/I projects
- Demonstrate a variety of proven technologies and rehabilitation techniques
- Represent typical I/I problems in the region
- Contribute to program goals (this "wild card" criterion was included for projects that could potentially satisfy conditions that were not anticipated during criteria development)

To aid the selection process, the County and local agency staff presented information about candidate basins, including flow data, age of sewer system, and type of pipe. Local agencies proposed 23 pilot projects for consideration. In April 2002, the local agencies reviewed and discussed the merits of each project, then voted to select the top 10 projects for construction. They selected nine basins to host distinct pilot projects and three basins to be combined into a single pilot project focused on manhole rehabilitation, for a total of 10 projects in 12 pilot basins.

The pilot projects included a mix of projects on public and private property in 12 local agency jurisdictions (Figure 3-4): City of Auburn, City of Brier, Skyway Water and Sewer District (formerly known as Bryn Mawr), Coal Creek Utility District, City of Kent, City of Kirkland, City of Lake Forest Park, City of Mercer Island, Northshore Utility District, City of Redmond, Ronald Wastewater District (formerly known as Shoreline Wastewater Management), and Val Vue Sewer District. The combined Coal Creek, Northshore, and Val Vue projects made up the "Manhole Project."

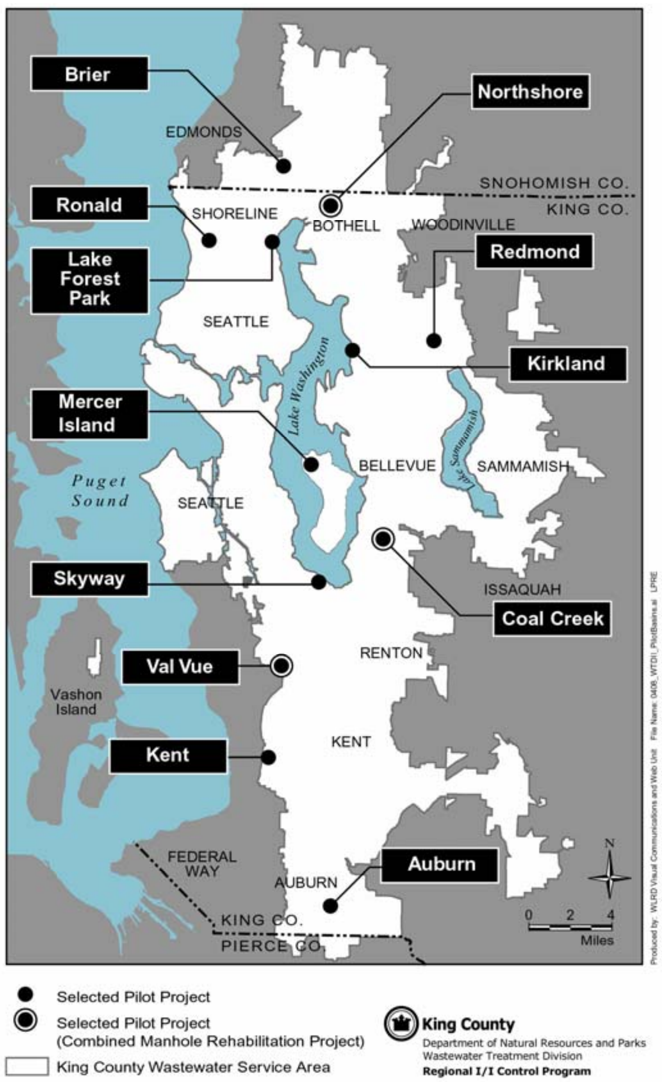

Figure 3-4. Pilot Project Locations

3.3.2.2 Pilot Project Approach

Work on each pilot project consisted of identifying I/I sources through field investigations, designing and constructing rehabilitation improvements, and monitoring post-construction flows to determine the effectiveness of the rehabilitation.

In the second half of 2002, sewer system evaluation surveys (SSES) were performed to support selection and detailed design of the I/I control technologies to be tested in each pilot project location. A key objective of the pilot projects was to gain experience with a variety of sewer system repair technologies in manholes, mains, laterals, and side sewers (Table 3-2). Technologies tested by the pilot projects included lining pipes using various cured-in-place materials, replacing pipes by pipe bursting or open-cut methods, replacing manholes, rehabilitating manholes by using chemical grouting or epoxy injection and by adjusting frames and covers, and installing cleanouts.

Table 3-2. Rehabilitation in Local Sewers

	Mains	Manholes	Laterals	Side Sewers
Auburn	●	●	●	●
Brier	●	●		
Coal Creek		●		
Kent			●	●
Kirkland	●	●	●	
Lake Forest Park	●	●		
Mercer Island	●			
Northshore		●		
Redmond	●	●	●	
Ronald			●	●
Skyway	●	●	●	●
Val Vue		●		

3.3.2.3 Pilot Project Results

The pilot projects provided valuable insights into implementation, costs, and I/I reduction rates. The most important lessons learned were as follows:

- Flow monitoring can detect sources and volumes of I/I
- Targeted sewer rehabilitation can reduce I/I
- A high percentage of I/I tends to originate in side sewers and laterals
- Strong collaboration between the County and local agencies was an important factor in successfully identifying, targeting, and reducing I/I

The projects illustrated that areas with I/I can be identified through comprehensive wet-weather flow monitoring and that identifying system defects is most effective when the SSES is completed during wet weather. Several sources of infiltration that eluded detection through the SSES completed during the dry season were subsequently identified during pilot project construction and post-rehabilitation inspection work completed during the wet season.

Rehabilitation technologies reduced I/I in eight of the ten pilot projects (Table 3-3). The highest reduction (87 percent) occurred in Skyway, where the entire system within the pilot project area was rehabilitated. Reductions in Kent (76 percent) and Ronald (74 percent) were also high. All three projects included rehabilitation of laterals and side sewers on private property. The high I/I reductions in these areas corroborate the assumption that a large percentage of I/I originates on private property. The relatively low reduction rate (37 percent) for the publicly owned sewer main rehabilitation project on Mercer Island further corroborates this assumption.

Pilot projects in Auburn and Redmond yielded no measurable I/I reduction, most likely because only a small percentage of each basin was rehabilitated and therefore the impact on the overall I/I rate was small. The Manhole Project resulted in no measurable reduction in Coal Creek and Val Vue and only 23 percent reduction in Northshore. These results suggest that very little I/I reduction can result from manhole rehabilitation alone.

Another important lesson learned was that I/I control would not have been possible without the support of local agencies and private property owners. Owners were engaged before, during, and after the projects through public information and education, property owner incentives, and active local agency participation. The owners helped to locate cleanouts and refrained from using the sewers during construction.

Finally, even though the greatest reductions may occur from rehabilitating side sewers and laterals, experience with the Skyway project and with expanded bids for the Kent and other projects indicates that rehabilitating sewer mains at the same time as side sewers and laterals can be done for a relatively small increase in cost.

The final construction cost for the 10 pilot projects was $7.8 million. Local agencies contributed $0.67 million; King County contributed the remaining $7.13 million. In addition to construction costs, total pilot project costs shown in Table 3-3 included costs for SSES, design, pre- and post-rehabilitation flow monitoring, construction management, modeling, and analysis.

Table 3-3. Summary of I/I Pilot Project Results

						20 Year Peak I/I[b]				
	Mains	Manholes (MH)	Laterals (L)	Side Sewers (SS)	% of Basin Improved[a]	Pre-Rehab (gpad)	Post-Rehab (gpad)	Reduction %	Construction Cost	Total Cost[d]
Auburn	●	●	●	●	11% of mains	8,900	8,900	NMR	$384,700	$749,400
Brier	●	●			23% of mains	10,100	5,000	50%	$372,700	$820,400
Kent			●	●	100% of L and SS	12,700	3,100	76%	$1,080,700	$1,446,900
Kirkland	●	●	●		25% of mains	11,000	7,900	28%	$838,200	$1,190,400
Lake Forest Park	●	●			35% of mains	22,500	7,100	69%	$790,400	$1,228,900
Manhole Project		●				17,800	16,300	23%[c]	$200,800	$660,200
Mercer Island	●				70% of mains	8,200	5,200	37%	$815,800	$1,218,600
Redmond	●	●	●		36% of mains	1,000	1,000	NMR	$840,100	$1,273,400
Ronald			●	●	72% of L and SS	18,200	4,800	74%	$1,077,300	$1,531,400
Skyway	●	●	●	●	100% of mains	63,200	8,400	87%	$1,395,200	$1,883,900

NMR = no measurable reduction.

[a] "% Improved" refers to the percentage of the identified elements of the sewer system that were rehabilitated during the pilot project.

[b] The 20-year peak pre-rehabilitation I/I rate is a model-predicted rate; the I/I rates used to select the pilot projects were the measured I/I rates for the maximum storm observed during the flow monitoring period.

[C] The pre- and post-rehabilitation flows shown for the Manhole Project are the combined flows for all three basins in the project. The 23 percent reduction occurred in the Northshore basin; there was no measurable reduction in the Coal Creek and Val Vue basins.

[d] In addition to construction costs, total pilot project costs include costs for SSES, design, pre- and post-rehabilitation flow monitoring, construction management, modeling, and analysis.